JC18 Rec'd PCT/PTO 30 APR 2001

FORM PTO-1390 (REV. 5-93) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER 2345/154
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371	U.S. APPLICATION NO. (If known, see 37 CFR 1.5) 09/830757

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED:
PCT/EP00/08261	**24 August 2000 (24.08.00)**	**30 August 1999 (30.08.99)**

JC07 Rec'd PCT/PTO 30 APR 2001

TITLE OF INVENTION
DEVICE AND METHOD FOR THE TEMPERATURE-INDEPENDENT OPERATION OF ELECTRO-OPTICAL SWITCHES ON THE BASIS OF FERROELECTRIC LIQUID CRYSTALS HAVING A DEFORMED HELIX

APPLICANT(S) FOR DO/EO/US
Wolfgang DULTZ, Dirk GANZKE, Wolfgang HAASE, Eugene POZHIDAEV

Applicant(s) herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) immediately rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☐ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)) UNSIGNED.
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A **FIRST** preliminary amendment.
    ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
14. ☒ A substitute specification and marked-up version of specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information: International Search Report and Form PCT/RO/101.

Express Mail No.:EL594612714US

NY01 369931 v 1

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U.S. APPLICATION NO. (if known, see 37 C.F.R. 1.5) 09/830757	INTERNATIONAL APPLICATION NO. PCT/EP00/08261	ATTORNEY'S DOCKET NUMBER 2345/154

				CALCULATIONS	PTO USE ONLY
17. ☒ The following fees are submitted: **Basic National Fee (37 CFR 1.492(a)(1)-(5)):** Search Report has been prepared by the EPO or JPO . . . . . . $860.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) . . . . . . $690.00 No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) . . . . . . $710.00 Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO . . . . . . $1,000.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) $100.00					
ENTER APPROPRIATE BASIC FEE AMOUNT =				$ 860	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				$	
Claims	Number Filed	Number Extra	Rate		
Total Claims	14 - 20 =	0	X $18.00	$0	
Independent Claims	2 - 3 =	0	X $80.00	$0	
Multiple dependent claim(s) (if applicable)			+ $270.00	$	
TOTAL OF ABOVE CALCULATIONS =				$860	
Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).				$	
SUBTOTAL =				$860	
Processing fee of $130.00 for furnishing the English translation later the ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$	
TOTAL NATIONAL FEE =				$860	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property +				$	
TOTAL FEES ENCLOSED =				$860	
				Amount to be refunded	$
				charged	$

a. ☐ A check in the amount of $________________ to cover the above fees is enclosed.

b. ☒ Please charge my Deposit Account No. 11-0600 in the amount of $860.00 to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 11-0600. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

By Reg No 35,952

SIGNATURE

Richard L. Mayer, Reg. No. 22,490
NAME

4/30/01
DATE

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PATENT TRADEMARK OFFICE

NY01 369931 v 1

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[2345/154]

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s)	:	Dultz et al.
Serial No.	:	To Be Assigned
Filed	:	Herewith
For	:	DEVICE AND METHOD FOR THE TEMPERATURE-INDEPENDENT OPERATION OF ELECTRO-OPTICAL SWITCHES ON THE BASIS OF FERROELECTRIC LIQUID CRYSTALS HAVING A DEFORMED HELIX
Examiner	:	To Be Assigned
Art Unit	:	To Be Assigned

Assistant Commissioner for Patents
Washington, D.C. 20231

PRELIMINARY AMENDMENT

SIR:

Kindly amend the above-identified application before examination, as set forth below.

IN THE TITLE:

Please replace the title with the following:

--DEVICE AND METHOD FOR THE TEMPERATURE-INDEPENDENT OPERATION OF ELECTRO-OPTICAL SWITCHES ON THE BASIS OF FERROELECTRIC LIQUID CRYSTALS HAVING A DEFORMED HELIX--.

IN THE SPECIFICATION:

Please amend the specification, including abstract, pursuant to the attached substitute specification. Also attached is a marked up version of the specification, indicating deleted and added sections. No new matter has been added.

IN THE CLAIMS:

Please cancel original claims 1-12, without prejudice.

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Please add the following new claims:

13. (New) An optical liquid crystal modulator, comprising:

at least one ferroelectric liquid crystal, wherein the at least one ferroelectric liquid crystal has a DHF mode and, at a location of the at least one ferroelectric liquid crystal, exhibits an operating range of an electric field of more than 20 V/μm.

14. (New) The optical liquid crystal modulator according to claim 13, wherein:

the liquid crystal modulator is configured as at least one $\lambda/2$ magnification plate which rotates in an electric field, and a single pass through the at least one $\lambda/2$ magnification plate produces at least one tilt angle of ± 22.5 degrees in the at least one $\lambda/2$ magnification plates.

15. (New) The optical liquid crystal modulator according to claim 13, further comprising:

a liquid crystalline mixture FLC-388.

16. (New) The optical liquid crystal modulator according to claim 13, wherein:

at a temperature of about 20.0° C, a helical pitch Po is between about 0.1 to about 0.5 μm.

17. (New) The optical liquid crystal modulator according to claim 13, wherein:

at a temperature of about 20.0° C, a helical pitch Po is about 0.22 μm.

18. (New) The optical liquid crystal modulator according to claim 13, further comprising:

a driving voltage of the liquid crystal modulator, wherein a driving frequency of the driving voltage is at least 10 kHz.

19. (New) The optical liquid crystal modulator according to claim 13, further comprising:

a driving voltage of the liquid crystal modulator, wherein a driving frequency of the driving voltage is greater than about 50 kHz.

20. (New) A method for operating an optical liquid crystal modulator having a ferroelectric liquid crystal, comprising:

operating the optical liquid crystal modulator at a location of the ferroelectric liquid crystal in an operating range of an electric field of greater than 20 V/μm,

wherein the ferroelectric liquid crystal has a DHF mode.

21. (New) The method for operating an optical liquid crystal modulator according to claim 20, wherein:

the ferroelectric liquid crystal is employed as at least one $\lambda/2$ magnification plate which rotates in an electric field and wherein in response to a single pass through the at least one $\lambda/2$ magnification plate a tilt angle of $\pm$ 22.5 degrees is produced in the at least one $\lambda/2$ magnification plate.

22. (New) The method for operating an optical liquid crystal modulator according to claim 20, wherein:

the ferroelectric liquid crystal is a liquid crystalline mixture FLC-388.

23. (New) The method for operating an optical liquid crystal modulator according to claim 20, wherein:

the ferroelectric liquid crystal has a helical pitch Po of about 0.1 to 0.5 at a temperature of about 20.0° C.

24. (New) The method for operating an optical liquid crystal modulator according to claim 20, wherein:

the ferroelectric liquid crystal has a helical pitch Po of about 0.22 μm at a temperature of about 20.0° C.

25. (New) The method for operating an optical liquid crystal modulator of claim 20, further comprising:

providing a driving frequency of a driving voltage of the optical liquid crystal modulator of at least 10 kHz.

26. (New) The method for operating an optical liquid crystal modulator of claim 20,

further comprising:

providing a driving frequency of a driving voltage of the optical liquid crystal modulator of greater than 50 kHz.

REMARKS

This Preliminary Amendment cancels, without prejudice, original claims 1-12 in the underlying PCT Application No. PCT/EP00/08261, and adds new claims 13-26. The new claims conform the claims to U.S. Patent and Trademark Office rules and do not add new matter to the application.

The amendments to the specification and abstract reflected in the substitute specification are to conform the specification and abstract to U.S. Patent and Trademark Office rules and to introduce changes made in the underlying PCT application, and do not introduce new matter into the application.

The underlying PCT Application No. PCT/EP00/08261 includes an International Search Report, issued December 22, 2000, a copy of which is included. The Search Report includes a list of documents that were considered by the Examiner in the underlying PCT application.

Applicants assert that the present invention is new, non-obvious, and useful. Prompt consideration and allowance of the claims are respectfully requested.

Respectfully Submitted,

KENYON & KENYON

Dated: 4/30/01

By: ______________________

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[2345/154]

DEVICE AND METHOD FOR THE TEMPERATURE-INDEPENDENT OPERATION OF ELECTRO-OPTICAL SWITCHES ON THE BASIS OF FERROELECTRIC LIQUID CRYSTALS HAVING A DEFORMED HELIX

Field of the Invention

The present invention is directed to a device for the temperature-independent operation of electro-optical switches on the basis of ferroelectric liquid crystals having a deformed helix.

Background Information

For some 20 years now, optical liquid crystals have fundamentally changed display technology. As economically priced light valves, they are also often used in the switching of the optical flow of information. The development of ferroelectric liquid crystals has moved switching times into the microsecond range. However, the fact that most of a liquid crystal's physical parameters are highly temperature dependent is still causing problems. Many technical instruments require that the components exhibit the same properties within a broad temperature range. In vehicle construction, in particular, temperature requirements are from -30° C through +80° C. Optical overload-protection switches in open-air video-monitoring systems can also be exposed to such temperatures.

Examples of other applications are birefringent interference filters, which are spectrally tuned with the aid of liquid crystals (C. BARTA, et al., Crystal Optical Interference Filter, European Patent 0 907 089 A2).

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So-called optically or electrically addressable, spatially resolving liquid crystal modulators (OASLM, EASLM), used to convert incoherent image information into coherent image information, were only able to be operated in conventional methods heretofore within narrow temperature ranges, since their switching times vary considerably in response to temperature.

Summary of the Invention

The present invention provides device and a method which will substantially reduce temperature-dependent influences and attendant long switching times.

The present invention further provides a device and a method where ferroelectric liquid crystals exhibit temperature-independent and very short switching times, within a broad range, and, therefore, can be used for optical open-air switches and in vehicles.

The present invention further provides for an optical liquid crystal modulator to be used, where the ferroelectric liquid crystals have a DHF mode and are preferably operated within a range of the electric field of more than 20V/μm. As a result, within a frequency range substantially above 50 kHZ, the modulator has a temperature-independent and extremely low response time.

Brief Description of the Drawings

Figure 1 shows the dependence of electric field E_c, necessary for complete winding of the helix, on the switching frequency f at T = 20.0°C, the measurement being performed on a 2.0 μm thick cell in the liquid crystalline mixture FLC-388, and the helical pitch Po, at a temperature T =

20.0°C, having the value of 0.22 μm, according to an embodiment of the present invention;

Figure 2 shows the dependence of switching time τ of effective tilt angle Θ_{eff} and of contrast ratio CR on the frequency of the electric field, having layer thickness d=1.8 μm, 20 V_{pp}, T=35°C, according to an embodiment of the present invention; and

Figure 3 shows the temperature dependence of switching time $\tau_{0.1-0.9}$ in the DHF mode at a frequency f = 130 kHz and E = ±15 V/μm (curve 1) and when switching the completely unwound state (E > E_u) at f=10 kHz and E = ±15 V/μm (curve 2), the temperature dependence of tilt angle Θ in the DHF mode at f = 130 kHz and E = ±15 V/μm (measuring curve 3) and in the unwound state at f = 10 kHz and E = 15 V/μm (curve 4).

Detailed Description

The present invention employs ferroelectric liquid crystals for modulating light in liquid crystal modulators, whose design, in particular external electrodes made of transparent material.

Ferroelectric liquid crystals are used, whose helix has a small pitch (< 300 μm) and is able to be continuously deformed through application of a small electric field (so-called DHF mode). This DHF mode allows for continuous varying of the effective tilt angle Θ_{eff} and the effective birefringence $\Delta\eta_{eff}$ at low voltages (< 5V) and short switching times (< 1ms). The effective tilt angle can be equivalent in size to half of the angle of rotation of the indicatrix of the liquid crystal in the electric field; i.e., the greater the effective tilt angle is, the more intense the rotation of the indicatrix of the liquid crystal.

Since optical liquid crystal modulators are designed on the basis of the DHF mode as $\lambda/2$ magnification plates which rotate in the electric field, a single pass through the plate requires tilt angles of ± 22.5 degrees in order to completely extinguish polarized light in the switching state "OFF" and obtain full transparency in the switching state "ON".

The electric field E_U, which is required for complete winding of the helix and which thereby induces the desired tilt angle, is relatively small at low frequencies (Figure 1, E_U ~0.5 through 1 V/μm at frequencies f smaller than 1 kHz). At higher frequencies, the field strength increases; in addition, the tilt angle also decreases. This may be seen in Figures 1 and 2.

At frequencies above 50 kHz, fields E_U> 20 V/μm are necessary in order to completely unwind the helix. Thus, the region in which the DHF effect can be utilized is shifted toward higher fields.

Since higher fields lead to higher voltages on the liquid crystal and, moreover, lead to smaller tilt angles, till now, this region was not considered to be interesting from a technical standpoint.

In the exemplary embodiment according to the present invention, Figure 1 depicts the dependency of electric field E_c, necessary for a complete winding of the helix, on switching frequency f at T = 20.0°C. The measurement was performed on a 2.0 μm thick cell in a self-produced liquid crystalline mixture FLC-388. The helical pitch Po amounts to 0.22 μm at a temperature of T = 20.0° C. In addition, at a temperature of approximately T = 20.0° C, i.e., at about room temperature, the helical pitch Po lies within a range of 0.1 to 0.5.

With higher frequencies, however, the response time τ can be lowered by more than one order of magnitude, while tilt angle θ remains virtually constant up to very high frequencies. See Figure 2. Thus, it may be that the contrast ratio and the birefringence also drop with the switching time, but acceptable values are still achieved for applications.

In the exemplary embodiment according to the present invention, Figure 2 illustrates the dependency of switching time τ of the effective tilt angle θ_{eff} and of the contrast ratio CR on the frequency of the electric field at a layer thickness of d = 1.8 μm and 20 V_{pp}, as well as at a temperature of T = 35°C.

In the exemplary embodiment according to the present invention, Figure 3 depicts a measurement of response time τ as a function of the temperature for such a liquid crystal system. While at 10 kHz, response time τ is heavily temperature-dependent for an operation of the liquid crystal (curve 2), at an operating frequency of 130 kHz, it is not only very short, but also absolutely thermally stable (curve 1). In this context, the effective tilt angle changes only slightly, and the temperature dependency (curve 3 + 4) does not become significant until temperatures greater than 50°C.

By extensively optimizing the mixtures, as expected, a high-speed liquid crystal switch is able to be developed in accordance with the present invention for an application range of -20 through 80° C.

Abstract

In order to substantially reduce temperature-dependent influences and attendant long switching times in the case of an optical liquid crystal modulator having at least one ferroelectric liquid crystal and in a method for operating an optical liquid crystal modulator, the ferroelectric liquid crystals are provided to have a DHF mode and to exhibit an operating range of an electric field of more than 20 V/μm at the location of the liquid crystal.

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DEVICE AND METHOD FOR THE TEMPERATURE-INDEPENDENT OPERATION OF ELECTRO-OPTICAL SWITCHES ON THE BASIS OF FERROELECTRIC LIQUID CRYSTALS HAVING A DEFORMED HELIX

Field of the Invention

The present invention is directed to a device[according to the definition of the species in Claim 1 and to a method according to the definition of the species in Claim 6] for the temperature-independent operation of electro-optical switches on the basis of ferroelectric liquid crystals having a deformed helix.

Background Information

For some 20 years now, optical liquid crystals have fundamentally changed display technology. As economically priced light valves, they are also often used in the switching of the optical flow of information. The development of ferroelectric liquid crystals has moved switching times into the microsecond range. However, the fact that most of a liquid crystal's physical parameters are highly temperature dependent is still causing problems. Many technical instruments require that the components exhibit the same properties within a broad temperature range. In vehicle construction, in particular, temperature requirements are from -30° C through +80° C. Optical overload-protection switches in open-air video-monitoring systems can also be exposed to such temperatures.

Examples of other applications are birefringent interference filters, which are spectrally tuned with the aid of liquid crystals (C. BARTA, et al., Crystal Optical Interference Filter, European Patent 0 907 089 A2).

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MARKED UP VERSION OF SPECIFICATION

So-called optically or electrically addressable, spatially resolving liquid crystal modulators (OASLM, EASLM), used to convert incoherent image information into coherent image information, were only able to be operated in [known]conventional methods heretofore within narrow temperature ranges, since their switching times vary considerably in response to temperature.

[The object]Summary of the Invention

The present invention [is, therefore, to alleviate the above-described disadvantages and to provide, in particular, a]provides device and a method which will substantially reduce temperature-dependent influences and attendant long switching times.

[This objective is achieved by a device having the features of Claim 1 and by a method having the features of Claim 6.

In accordance with the]The present invention[,] further provides a device and a method[are provided,] where ferroelectric liquid crystals exhibit temperature-independent and very short switching times, within a broad range, and, therefore, can be used [quite advantageously]for optical open-air switches and in vehicles.

The present invention [advantageously]further provides for an optical liquid crystal modulator to be used, where the ferroelectric liquid crystals have a DHF mode and are preferably operated within a range of the electric field of more than 20V/μm. As a result, within a frequency range substantially above 50 kHZ, the modulator has a temperature-independent and extremely low response time.

[On the basis of preferred exemplary embodiments and with reference to the enclosed drawing, the present invention

is described in greater detail in the following. The figures show:

Figure 1: The]Brief Description of the Drawings

Figure 1 shows the dependence of electric field E_c, necessary for complete winding of the helix, on the switching frequency f at T = 20.0°C, the measurement being performed on a 2.0 μm thick cell in the liquid crystalline mixture FLC-388, and the helical pitch Po, at a temperature T = 20.0°C, having the value of 0.22 μm, according to an embodiment of the present invention;

Figure 2[:] [T]shows the dependence of switching time τ of effective tilt angle θ_{eff} and of contrast ratio CR on the frequency of the electric field[. L], having layer thickness d=1.8 μm, [
]20 V_{pp}, T=35°C, according to an embodiment of the present invention; and

Figure 3[:] [T]shows the temperature dependence of switching time $\tau_{0.1-0.9}$ in the DHF mode at a frequency f = 130 kHz and [
]E = ±15 V/μm (curve 1) and when switching the completely unwound state ($E > E_u$) at f=10 kHz and [
]E = ±15 V/μm (curve 2), the temperature dependence of tilt angle θ in the DHF mode at f = 130 kHz and [
]E = ±15 V/μm (measuring curve 3) and in the unwound state at f = 10 kHz and E = 15 V/μm (curve 4).

[
Summary of the Invention]Detailed Description

The present invention employs ferroelectric liquid crystals for modulating light in liquid crystal

MARKED UP VERSION OF SPECIFICATION

modulators, whose design, in particular external electrodes made [especially]of transparent material[, and whose cells are well known to one skilled in the art in this field, so that there is no need to describe the mechanical and electrical set-up in greater detail].

Ferroelectric liquid crystals are used, whose helix has a small pitch (< 300 μm) and is able to be continuously deformed through application of a small electric field (so-called DHF mode). This DHF mode [makes it possible to]allows for continuous[ly vary] varying of the effective tilt angle θ_{eff} and the effective birefringence Δn_{eff} at low voltages (< 5V) and short switching times (< 1ms). The effective tilt angle [is]can be equivalent in size to half of the angle of rotation of the indicatrix of the liquid crystal in the electric field; i.e., the greater the effective tilt angle is, the more intense the rotation of the indicatrix of the liquid crystal.

Since optical liquid crystal modulators are designed on the basis of the DHF mode as [lambda/2]$\lambda/2$ magnification plates which rotate in the electric field, a single pass through the plate requires tilt angles of ± 22.5 degrees in order to completely extinguish polarized light in the switching state "OFF" and obtain full transparency in the switching state "ON".

The electric field E_U, which is required for complete winding of the helix and which thereby induces the desired tilt angle, is relatively small at low frequencies (Figure 1, E_U ~0.5 through 1 V/μm at frequencies f smaller than 1 kHz). At higher frequencies, [this critical]the field strength increases; in addition, the tilt angle also decreases[; see]. This may be seen in Figures 1 and 2.

At frequencies above 50 kHz, fields E_U> 20 V/μm are necessary in order to completely unwind the helix. Thus,

the region in which the DHF effect can be utilized is shifted toward higher fields.

Since higher fields [are disadvantageous due]lead to[the] higher voltages on the liquid crystal and, moreover, lead to smaller tilt angles, till now, this region was not considered to be interesting from a technical standpoint.

In the exemplary embodiment according to the present invention, Figure 1 depicts the dependency of electric field E_c, necessary for a complete winding of the helix, on switching frequency f at T = 20.0°C. The measurement was performed on a 2.0 μm thick cell in a self-produced liquid crystalline mixture FLC-388. The helical pitch Po amounts to 0.22 μm at a temperature of T = 20.0° C. In addition, at a temperature of approximately T = 20.0° C, i.e., at about room temperature, the helical pitch Po lies within a range of 0.1 to 0.5.

With higher frequencies, however, the response time τ [is]can be lowered by more than one order of magnitude, while tilt angle θ remains virtually constant up to very high frequencies[(]. See Figure 2[)]. Thus, it may be that the contrast ratio and the birefringence also drop with the switching time, but acceptable values are still achieved for applications.

In the exemplary embodiment according to the present invention, Figure 2 illustrates the dependency of switching time τ of the effective tilt angle θ_{eff} and of the contrast ratio CR on the frequency of the electric field at a layer thickness of [ ]d = 1.8 μm and 20 V_{pp}, as well as at a temperature of T = 35°C.

[As an example]In the exemplary embodiment according to the present invention, Figure 3 depicts a measurement of

response time τ as a function of the temperature for such a liquid crystal system. While at 10 kHz, response time τ is heavily temperature-dependent for an operation of the liquid crystal (curve 2), at an operating frequency of 130 kHz, it is not only very short, but also absolutely thermally stable (curve 1). In this context, the effective tilt angle changes only slightly, and the temperature dependency (curve 3 + 4) does not become significant until temperatures greater than 50°C.

By extensively optimizing the mixtures, as expected, a high-speed liquid crystal switch is able to be developed in accordance with the present invention for an application range of -20 through 80° C.

Abstract

In order to substantially reduce temperature-dependent influences and attendant long switching times in the case of an optical liquid crystal modulator having at least one ferroelectric liquid crystal and in a method for operating an optical liquid crystal modulator, [it is provided for]the ferroelectric liquid crystals are provided to have a DHF mode and to exhibit an operating range of [the]an electric field of more than 20 V/μm at the location of the liquid crystal.

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DEVICE AND METHOD FOR THE TEMPERATURE-INDEPENDENT OPERATION OF ELECTRO-OPTICAL SWITCHES ON THE BASIS OF FERROELECTRIC LIQUID CRYSTALS HAVING A DEFORMED HELIX

The present invention is directed to a device according to the definition of the species in Claim 1 and to a method according to the definition of the species in Claim 6 for the temperature-independent operation of electro-optical switches on the basis of ferroelectric liquid crystals having a deformed helix.

For some 20 years now, optical liquid crystals have fundamentally changed display technology. As economically priced light valves, they are also often used in the switching of the optical flow of information. The development of ferroelectric liquid crystals has moved switching times into the microsecond range. However, the fact that most of a liquid crystal's physical parameters are highly temperature dependent is still causing problems. Many technical instruments require that the components exhibit the same properties within a broad temperature range. In vehicle construction, in particular, temperature requirements are from -30° C through +80° C. Optical overload-protection switches in open-air video-monitoring systems can also be exposed to such temperatures.

Examples of other applications are birefringent interference filters, which are spectrally tuned with the aid of liquid crystals (C. BARTA, et al., Crystal Optical Interference Filter, European Patent 0 907 089 A2).

So-called optically or electrically addressable, spatially resolving liquid crystal modulators (OASLM, EASLM), used to convert incoherent image information into

coherent image information, were only able to be operated in known methods heretofore within narrow temperature ranges, since their switching times vary considerably in response to temperature.

The object of the present invention is, therefore, to alleviate the above-described disadvantages and to provide, in particular, a device and a method which will substantially reduce temperature-dependent influences and attendant long switching times.

This objective is achieved by a device having the features of Claim 1 and by a method having the features of Claim 6.

In accordance with the present invention, a device and a method are provided, where ferroelectric liquid crystals exhibit temperature-independent and very short switching times, within a broad range, and, therefore, can be used quite advantageously for optical open-air switches and in vehicles.

The present invention advantageously provides for an optical liquid crystal modulator to be used, where the ferroelectric liquid crystals have a DHF mode and are preferably operated within a range of the electric field of more than 20V/μm. As a result, within a frequency range substantially above 50 kHZ, the modulator has a temperature-independent and extremely low response time.

On the basis of preferred exemplary embodiments and with reference to the enclosed drawing, the present invention is described in greater detail in the following. The figures show:

Figure 1: The dependence of electric field E_c, necessary for complete winding of the helix, on the

switching frequency f at T = 20.0°C, the measurement being performed on a 2.0 μm thick cell in the liquid crystalline mixture FLC-388, and the helical pitch Po, at a temperature T = 20.0°C, having the value of 0.22 μm;

Figure 2: The dependence of switching time τ of effective tilt angle θ_{eff} and of contrast ratio CR on the frequency of the electric field. Layer thickness d=1.8 μm, 20 V_{pp}, T=35°C;

Figure 3: The temperature dependence of switching time $\tau_{0.1-0.9}$ in the DHF mode at a frequency f = 130 kHz and E = ±15 V/μm (curve 1) and when switching the completely unwound state (E > E_u) at f=10 kHz and E = ±15 V/μm (curve 2), the temperature dependence of tilt angle θ in the DHF mode at f = 130 kHz and E = ±15 V/μm (measuring curve 3) and in the unwound state at f = 10 kHz and E = 15 V/μm (curve 4).

Summary of the Invention

The present invention employs ferroelectric liquid crystals for modulating light in liquid crystal modulators, whose design, in particular external electrodes made especially of transparent material, and whose cells are well known to one skilled in the art in this field, so that there is no need to describe the mechanical and electrical set-up in greater detail.

Ferroelectric liquid crystals are used, whose helix has a small pitch (< 300 μm) and is able to be continuously

deformed through application of a small electric field (so-called DHF mode). This DHF mode makes it possible to continuously vary the effective tilt angle Θ_{eff} and the effective birefringence Δn_{eff} at low voltages (< 5V) and short switching times (< 1ms). The effective tilt angle is equivalent in size to half of the angle of rotation of the indicatrix of the liquid crystal in the electric field; i.e., the greater the effective tilt angle is, the more intense the rotation of the indicatrix of the liquid crystal.

Since optical liquid crystal modulators are designed on the basis of the DHF mode as lambda/2 magnification plates which rotate in the electric field, a single pass through the plate requires tilt angles of ± 22.5 degrees in order to completely extinguish polarized light in the switching state "OFF" and obtain full transparency in the switching state "ON".

The electric field E_U, which is required for complete winding of the helix and which thereby induces the desired tilt angle, is relatively small at low frequencies (Figure 1, E_U ~0.5 through 1 V/μm at frequencies f smaller than 1 kHz). At higher frequencies, this critical field strength increases; in addition, the tilt angle also decreases; see Figures 1 and 2.

At frequencies above 50 kHz, fields E_U> 20 V/μm are necessary in order to completely unwind the helix. Thus, the region in which the DHF effect can be utilized is shifted toward higher fields.

Since higher fields are disadvantageous due to the higher voltages on the liquid crystal and, moreover, lead to smaller tilt angles, till now, this region was not considered to be interesting from a technical standpoint.

Figure 1 depicts the dependency of electric field E_c, necessary for a complete winding of the helix, on switching frequency f at T = 20.0°C. The measurement was performed on a 2.0 μm thick cell in a self-produced liquid crystalline mixture FLC-388. The helical pitch Po amounts to 0.22 μm at a temperature of T = 20.0° C. In addition, at a temperature of approximately T = 20.0° C, i.e., at about room temperature, the helical pitch Po lies within a range of 0.1 to 0.5.

With higher frequencies, however, the response time τ is lowered by more than one order of magnitude, while tilt angle θ remains virtually constant up to very high frequencies (Figure 2). Thus, it may be that the contrast ratio and the birefringence also drop with the switching time, but acceptable values are still achieved for applications.

Figure 2 illustrates the dependency of switching time τ of the effective tilt angle θ_{eff} and of the contrast ratio CR on the frequency of the electric field at a layer thickness of

d = 1.8 μm and 20 V_{pp}, as well as at a temperature of T = 35°C.

As an example, Figure 3 depicts a measurement of response time τ as a function of the temperature for such a liquid crystal system. While at 10 kHz, response time τ is heavily temperature-dependent for an operation of the liquid crystal (curve 2), at an operating frequency of 130 kHz, it is not only very short, but also absolutely thermally stable (curve 1). In this context, the effective tilt angle changes only slightly, and the temperature dependency (curve 3 + 4) does not become significant until temperatures greater than 50°C.

By extensively optimizing the mixtures, as expected, a

high-speed liquid crystal switch is able to be developed in accordance with the present invention for an application range of -20 through 80° C.

What is claimed is

1. An optical liquid crystal modulator having at least one ferroelectric liquid crystal,
wherein the ferroelectric liquid crystals have a DHF mode and, at the location of the liquid crystal, exhibit an operating range of the electric field of more than 20 V/μm.

2. The optical liquid crystal modulator as recited in Claim 1,
wherein the liquid crystal modulator having the DHF mode is designed as lambda/2 magnification plates which rotate in the electric field, and, in response to a single pass through the plate, tilt angles of $\pm$ 22.5 degrees are produced.

3. The optical liquid crystal modulator as recited in Claim 1 or 2, wherein the liquid crystal modulator encompasses a liquid crystalline mixture FLC-388.

4. The optical liquid crystal modulator as recited in Claim 1, 2 or 3, wherein, at a temperature of approximately T = 20.0° C, the helical pitch Po is within a range of 0.1 to 0.5.

5. The optical liquid crystal modulator as recited in Claim 4, wherein, at a temperature of approximately T = 20.0° C, the helical pitch Po is about 0.22 μm.

6. The optical liquid crystal modulator as recited in one of the preceding claims, wherein the driving frequency of the driving voltage of the liquid crystal modulator amounts to at least 10 kHz and, preferably, is above 50 kHz.

7. A method for operating an optical liquid crystal modulator having a ferroelectric liquid crystal, and, in particular, a liquid crystal modulator as recited in one of Claims 1 through 6,
wherein the ferroelectric liquid crystals have a DHF mode and are operated at the location of the liquid crystal in an operating range of the electric field of more than 20 V/μm.

8. The method for operating an optical liquid crystal modulator as recited in Claim 7,
wherein the liquid crystal modulator having the DHF mode is employed as lambda/2 magnification plates which rotate in the electric field, and, in response to a single pass through the plate, tilt angles of $\pm$ 22.5 degrees are produced.

9. The method for operating an optical liquid crystal modulator as recited in Claim 7 or 8,
wherein a liquid crystalline mixture FLC-388 is used for the ferroelectric liquid crystal.

10. The method for operating an optical liquid crystal modulator as recited in Claim 7, 8 or 9,
wherein a liquid crystal is used, whose helical pitch Po is within a range of 0.1 to 0.5 at a temperature of approximately T = 20.0° C.

11. The method for operating an optical liquid crystal modulator as recited in Claim 10,
wherein a ferroelectric liquid crystal is used, whose helical pitch Po is about 0.22 μm at a temperature of approximately T = 20.0° C.

12. The method for operating an optical liquid crystal modulator as recited in one of the preceding Claims 7 through 11,
wherein the driving frequency of the driving voltage of the liquid crystal modulator is at least 10 kHz and, preferably, is above 50 kHz.

Abstract

In order to substantially reduce temperature-dependent influences and attendant long switching times in the case of an optical liquid crystal modulator having at least one ferroelectric liquid crystal and in a method for operating an optical liquid crystal modulator, it is provided for the ferroelectric liquid crystals to have a DHF mode and to exhibit an operating range of the electric field of more than 20 V/μm at the location of the liquid crystal.

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am an original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled **DEVICE AND METHOD FOR THE TEMPERATURE-INDEPENDENT OPERATION OF ELECTRO-OPTICAL SWITCHES ON THE BASIS OF FERROELECTRIC LIQUID CRYSTALS HAVING A DEFORMED HELIX**, the specification of which was filed as International Application No. PCT/EP00/08261 on August 24, 2000 and filed as a U.S. application having Serial No. 09/830757 on April 30, 2001 for Letters Patent in the U.S.P.T.O.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims.

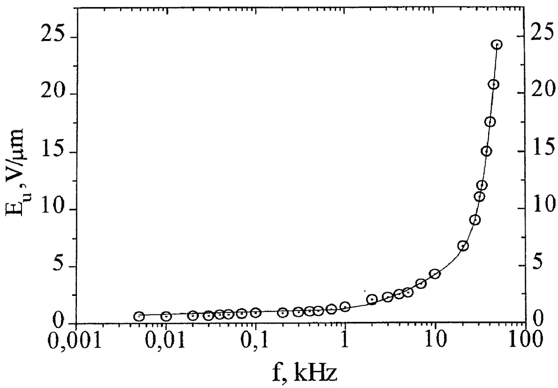
I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application(s) for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

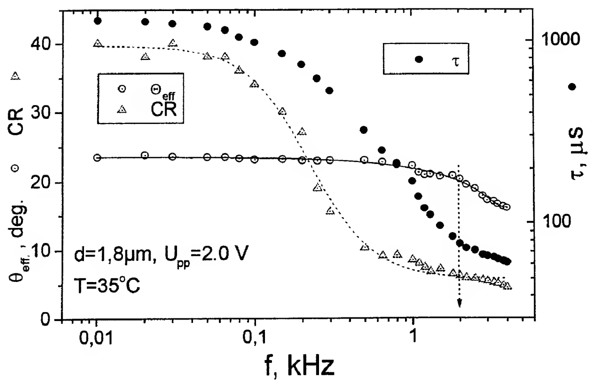
Number	Country Filed	Day/Month/Year	Priority Claimed Under 35 USC 119
199 410 79.8	Fed. Rep. of Germany	30 August 1999	Yes

Express Mail No. EL244507366US



25
20
15
10
5
0
E_u, V/µm
0,001
0,01
0,1
1
10
100
f, kHz

Fig. 1



θ_eff, deg. ⊙ CR △
40
30
20
10
0
1000
100
τ, µs
τ
Θ_eff
CR
d=1,8µm, U_pp=2.0 V
T=35°C
0,01
0,1
1
f, kHz

Fig. 2

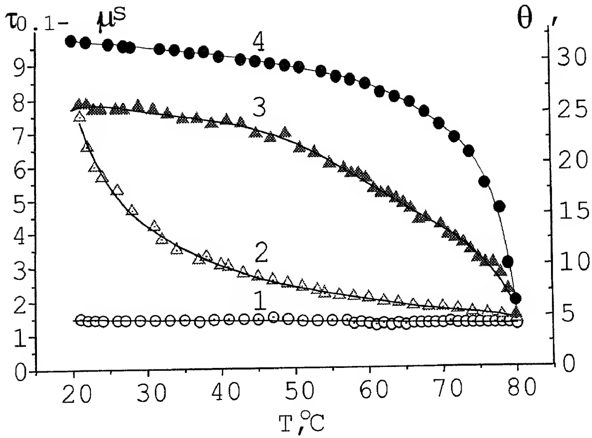

$\tau_{0.1}$- μs
θ, '
4
3
2
1
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30
20
30
40
50
60
70
80
T,°C

Fig. 3

And I hereby appoint Richard L. Mayer (Reg. No. 22,490), Gerard A. Messina (Reg. No. 35,952) and Linda M. Shudy (Reg. No. 47,084) my attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful and false statements may jeopardize the validity of the application or any patent issued thereon.

1-00

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